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PHOSPHATE REMOVAL BY ACTIVATED SLUDGE. AMENABILITY STUDIES AT SMITHFIELD, NORTH CAROLINA

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Robert S. Kerr Water Research Center
Ada, Oklahoma

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ROBERT S. KERR WATER RESEARCH CENTER
ADA, OKLAHOMA

NOVEMBER 1968

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PHOSPHATE REMOVAL BY ACTIVATED SLUDGE

Amenability Studies at Smithfield, North Carolina

by

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ABSTRACT

Orthophosphate removal by activated sludge was investigated in pilot and plant scale at the Smithfield, North Carolina waste treatment plant. These studies showed that the plant's secondary treatment process was not removing orthophosphate. Pilot studies in which sludge was acclimated in aerated jugs over a period of time showed removals reaching 65 to 90 percent.

INTRODUCTION

This report describes investigations at the Smithfield, North Carolina waste treatment plant in a continuing research program concerned with the removal of phosphate from municipal sewage by the activated sludge process. Field research conducted at San Antonio, Texas, showed that high removals of orthophosphate ($O\text{-}PO_4$) were accomplished in the aeration tanks. The efficiency of the process was found to be controlled by the operational parameters: aeration detention time, air supplied, mixed liquor suspended solids (MLSS) concentration, biochemical oxygen demand (BOD) load, phosphate load, rapid solid-liquid separation, minimum solids detention time in the final clarifiers, and separate disposal of phosphate concentrates.

The purposes of the amenability studies conducted were:

1. To determine by pilot and plant investigations if biological phosphate removal is feasible in municipalities of various geographical locations, populations served, and sewage characteristics.

2. To locate six or more activated sludge plants in various geographical regions to be used for demonstration of biological phosphate removal by operation in accordance with parameters identified at San Antonio.

3. To locate one activated sludge plant of suitable design and operational flexibility for use as a full-scale research plant to further specify, define, and optimize the biological phosphate removal process.

4. To verify on pilot scale that biological phosphate removal can be controlled by the parameters identified at San Antonio and/or isolate and identify additional controlling parameters.

Aerated jugs of mixed liquor have been shown[1] to simulate an aeration tank. The technique circumvents many of the limitations exerted by normal operational characteristics in activated sludge plants, such as control of aeration rate, sewage flow, total suspended solids (TSS) concentration, and phosphate and biochemcial oxygen demand (BOD) loadings. Sludge solids and waste from various points in the secondary system may be conveniently studied. Detention time of the mixed liquor in the aeration jug system is rigidly controlled. For these reasons, the method was selected as the means of testing the amenability of the waste and activated sludge to phosphate removal.

By deliberate variation of the operational parameters, the conditions for sludge response and maximum phosphate removal can be established. These amenability studies will indicate those waste and activated sludges most readily adaptable and, in conjunction with plant investigations, will aid in specifying operational levels, design changes, or sludge adaptability necessary to attain phosphate removal in the full-scale plant.

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[1]Scalf, M. R., et al., "Phosphate Removal by Activated Sludge, Amenability Studies at Baltimore, Maryland," USDI, FWPCA, Robert S. Kerr Water Research Center, Ada, Oklahoma. June 1968.

Experimental Procedures

Plant Analysis

The Smithfield, North Carolina plant was studied to determine pertinent design and operational characteristics. Programs of plant sampling and tracer studies were carried out in addition to jug studies to determine plant performance.

Plant records were examined for type and frequency of sewage flow, plant loading of BOD, suspended solids, and orthophosphate concentrations, analyses of chemical and physical parameters, and performance characteristics. Plant personnel were questioned as to sampling practices, analytical procedures, anomalies of wastes being treated, and peculiarities of operational control. The schedules for wasting raw and activated sludges were determined. Disposal methods of waste activated sludge, primary sludge, digester supernatant, sludge thickener supernatant, drying bed underflow, and other waste streams were studied in anticipation of auxiliary, inhibitory, or latent effects on the phosphate removal process.

Tracer studies were conducted using Rhodamine WT* dye on an aeration tank to determine hydraulic characteristics such as detention, short circuiting, and degree of longitudinal mixing.

Grab samples were collected throughout the plant to determine the phosphate levels and degree of removal. These samples were analyzed for concentration of orthophosphate and, occasionally, total phosphates ($T\text{-}PO_4$) and suspended solids. The sample sources

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*See Page 25.

were raw sewage, primary effluent (PE), return sludge (RS), aeration tank influent, aeration tank effluent, and final effluent (FE). Occasionally, supernatant samples were taken from digestion tanks. Dissolved oxygen (DO) measurements were made throughout the plant in conjunction with the sampling program.

Aeration Jug Studies

Return sludge or mixed liquor from various points in the secondary system was mixed with primary effluent or raw sewage to obtain the desired range of suspended solids concentration. The mixtures were prepared in five-gallon polyethylene jugs for subsequent aeration.

A portable air compressor was used as the air supply. Air was delivered through a manifold containing individual needle valves and rotometers for each jug. Polyethylene tee fittings were used as diffusers. The air flow was maintained constant throughout the experiment, except where noted.

The dissolved oxygen content and the temperature of the mixed liquor were monitored several times during each run.

Samples were withdrawn from the jugs usually at half-hour or hourly intervals. Preceding sample collection, approximately 200 ml of mixed liquor was siphoned through a withdrawal tube for purging and returned to the original jug. A volume of 100 ml was sufficient for orthophosphate analysis, and 250 ml was taken when additional analyses were planned.

RESULTS AND DISCUSSIONS

Plant Characteristics

The Smithfield, North Carolina waste treatment plant is composed of primary clarification followed by a conventional activated sludge secondary treatment system as shown in Figure 1.

The activated sludge system consists of two single-pass aeration tanks and two final clarifiers. Average primary effluent flow to these units is 1.0 million gallons per day (mgd) of primary effluent plus 0.5 to 0.75 mgd of return sludge. Mixed liquor suspended solids during the study period were in the range of 4,000 to 4,500 mg/l. Air supplied to the aeration tanks was approximately 2.9 cubic feet per gallon of sewage treated. Dissolved oxygen content in the aeration tanks ranged from 1.6 mg/l at the influent to 0.6 mg/l at the effluent end.

The average BOD of the primary and final effluents was 165 and 10 mg/l, respectively.

The primary clarifier influent is a combined raw sewage and waste activated sludge. Digester supernatant is mixed with primary effluent prior to entry to the aeration tanks. These additions to the raw sewage and primary effluent are made on an irregular schedule and at variable rates, and quantity is not always measured. Except for the small amount of phosphate in the digested sludge, the plant, therefore, functions as a closed system in regard to the phosphate removal process being investigated.

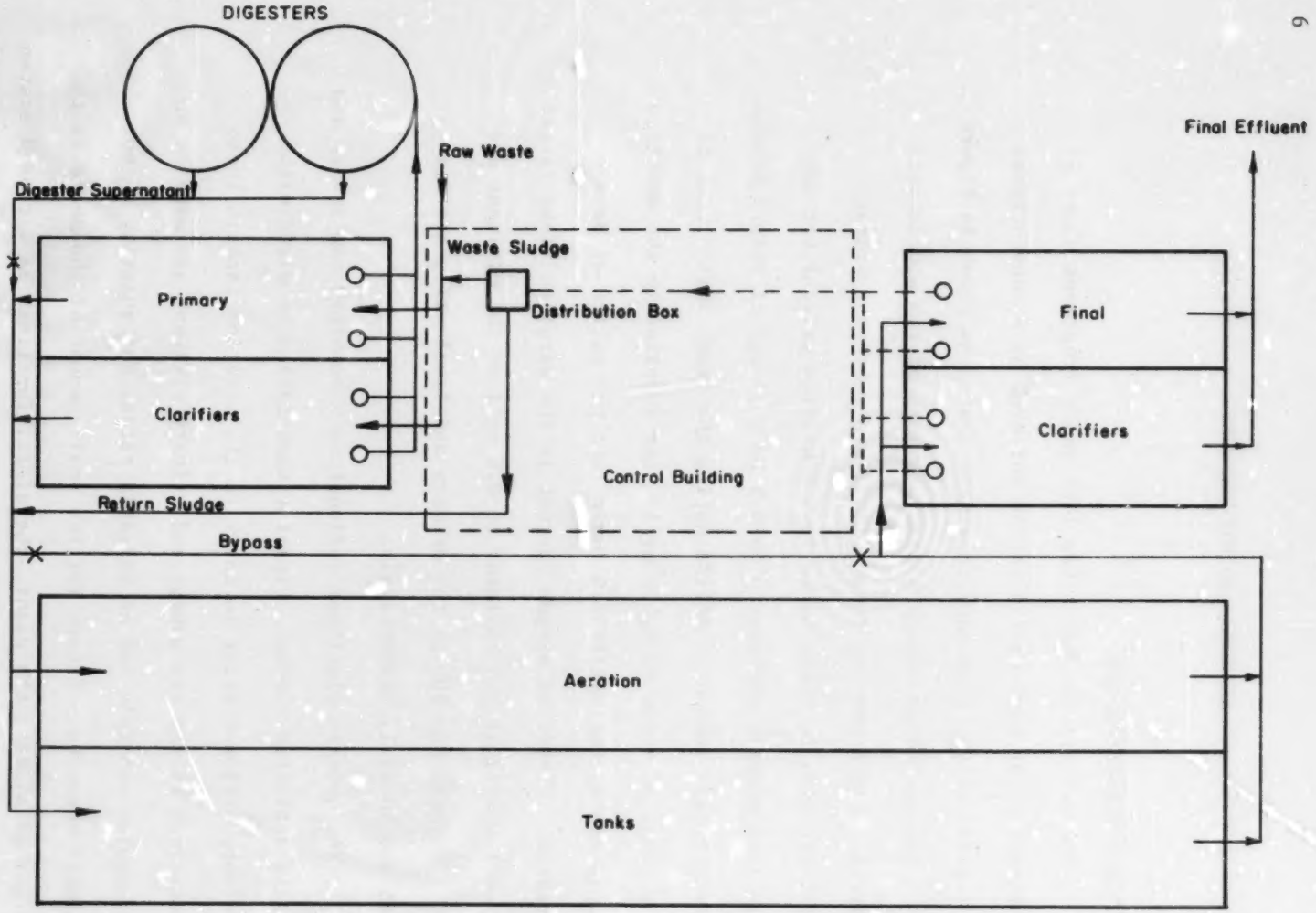

FIGURE 1 - SEWAGE TREATMENT PLANT, SMITHFIELD, NORTH CAROLINA

During the study period, however, digester supernatant was not added to the primary effluent.

Digested sludge is utilized on the grounds around the plant and is available to anyone who will haul it away.

Detention Studies

Dye tracer studies were conducted on March 18, 1967, to determine the hydraulic characteristics of the mixed liquor in the aeration tanks. The mixed liquor flow was 1.9 mgd.

Eleven-hundred ml of a 20 percent Rhodamine WT dye solution was introduced as a tracer into the head end of one 288,000-gallon aeration tank at 9:30 a.m. The dye concentration was monitored at the mid-point and effluent end.

Figure 2 shows dye concentration versus time at the half-point and effluent end of the tank. Both curves are skewed, the modal detention time at the effluent end being 1 hour. The mean detention time was 2.5 hours. The theoretical displacement time was 7 hours. These distribution curves describe hydraulic conditions for a system with considerable mixing and short circuiting

These results when compared to the near plug-flow hydraulics obtained at San Antonio show that the Smithfield tanks would not be suitable to demonstrate the biological phosphate removal process without modification. However, the preliminary survey indicated that two tanks could be operated in series with minor modification to improve hydraulic efficiency.

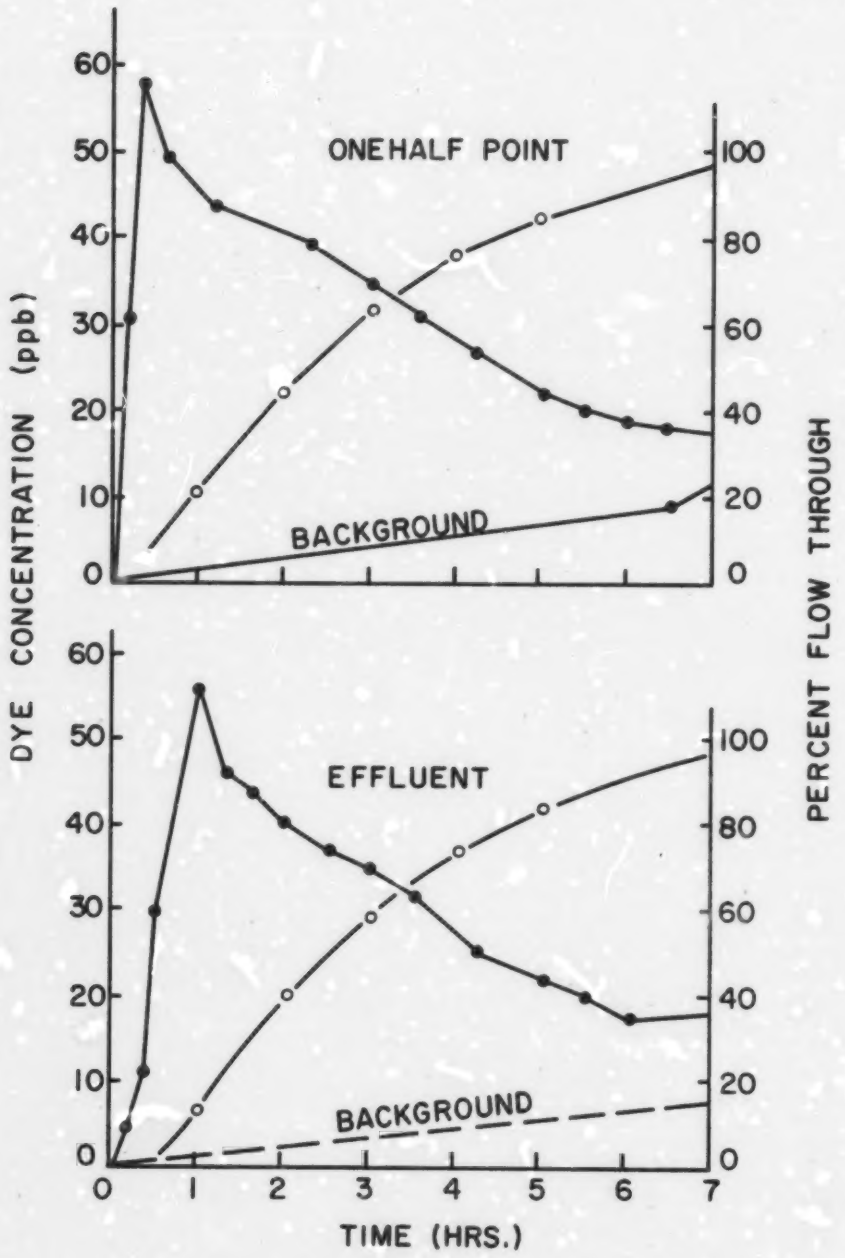

FIGURE 2 - DYE DETENTION IN AERATION TANK

Plant Performance

Samples were collected from the various processes in the plant and analyzed to determine typical concentrations of soluble orthophosphate and suspended solids. Such determinations indicate plant performance with regard to phosphate removal. Table 1 shows results from plant sampling.

Table 1

Plant Monitoring Summary
(mg/l)

Sample Point	O-PO as P	TSS	DO*
Raw Sewage	2.6	206	2.0
Primary Effluent	3.4	58	3.1
Aeration Tank No. 1			
Head	6.9	4,288	1.6
One-half point	7.1	-	1.1
End	7.3	-	0.6
Aeration Tank No. 2			
Head	7.7	4,372	-
One-half point	7.9	-	-
End	8.2	-	-
FE	7.8	-	4.6
Return Sludge	8.1	11,034	3.1
Digester Supernatant	64.0	-	-
Tap Water	0.06	-	-

*Temperature 14°C.

For one week prior to and during the study, digester supernatant was not returned to the aeration tanks. The data show that insoluble or condensed phosphate was converted to soluble

orthophosphate during primary and secondary treatment.

The high suspended solids concentration in the aeration tanks was considered necessary by plant personnel to control foaming. The final effluent contained 156 mg/l TSS. A light pinpoint floc was consistently observed in the final clarifiers and effluent.

Dissolved oxygen concentration at the head of the aeration tanks was 1.6 mg/l, but dropped to 0.6 mg/l at the effluent end. These values, while adequate for reduction of biodegradable substances, are not considered sufficient for high orthophosphate removal.

Aeration Jug Studies

A series of experiments devised from the San Antonio studies was used to test the sewage and sludge with regard to soluble orthophosphate removal. The results from these experiments serve as a guide to the disposition of plants tested with respect to utilization for process demonstration. Factors shown to affect the rate and magnitude of soluble orthophosphate removal are: suspended solids, BOD, and initial soluble orthophosphate concentrations. The ability of various sludges to remove soluble orthophosphate has been enhanced by subjecting the sludge to a period of "acclimation." Acclimation as referred to in this report was accomplished by feeding a BOD rich substrate to an aerated primary effluent-return sludge mixture for 8 to 20 hours. After the aeration period, the mixture was settled, the supernatant decanted, and fresh primary effluent added. The sludge response was measured by determining the amount of orthophosphate removed during the subsequent aeration period. The feeding

and response processes were repeated until orthophosphate removal was accomplished. Removal of orthophosphate indicates that the sludge and sewage can be amenable to the biological phosphate removal process.

1. Suspended Solids Variation

Two sets of five jugs each were prepared on March 20 and 21, 1967, respectively, to determine optimum suspended solids concentration for soluble orthophosphate removal at the Smithfield, North Carolina sewage treatment plant. Jug components are shown in Table 2. The suspended solids concentration range studied was 658 to 4,908 mg/l. DO values were over 3.0 mg/l for all jugs throughout the runs. The results are recorded in Table 3. None of the jugs removed soluble orthophosphate; rather, the concentration increased during the aeration period. Thus, optimum suspended solids concentration was not realized under the test conditions used.

2. BOD Variation

A set of four jugs was prepared on March 22, 1967, to determine the effect of supplemental BOD on soluble orthophosphate removal. The jugs contained aeration tank mixed liquor plus Metrecal.* The Metracal added represented 145, 290, 435, and 580 mg/l BOD, respectively. The results and jug components are recorded in Table 4.

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*See Page 25.

Table 2

SUSPENDED SOLIDS VARIATION

Components Jug
(Aeration Rate - 15 l/min.)

Low Range Solids, March 20, 1967

Jug No.	Liters of Component Added		
	PE	RS	FE
1	10	0.77	4.23
2	10	1.54	3.46
3	10	2.31	2.69
4	10	3.08	1.92
5	10	3.78	1.22

High Range Solids, March 21, 1967

Jug No.	Liters Of Component Added			
	PE	RS	RS*	FE
1	10	3.78	--	1.22
2	10	6.	3.	2.0
3	10	6.	3.3	1.7
4	10	7.5	5.	--
6	10	7.5	5.	--

* Return sludge volume concentrated by settling.

TABLE 3

SUSPENDED SOLIDS VARIATION

Analytical Results
(mg/l)

Low Range Solids, March 20, 1967

Aeration Time-Hrs	Jug No. 1	2	3	4	5
			$O\text{-}PO_4\text{-}P$		
0 (11:00 am)	5.6	5.7	6.0	5.8	5.8
1	5.6	5.6	5.6	5.7	6.8
2	5.5	5.6	5.6	5.9	6.0
3	5.7	5.7	5.8	6.1	5.0
4	5.4	5.5	5.6	5.6	5.8
5	5.4	5.5	5.9	5.9	6.0
6	5.6	6.4	6.1	6.1	6.1
MLSS	658	1,262	1,720	2,332	3,004

High Range Solids, March 21, 1967

Aeration Time-Hrs	Jug No. 1	2	3	4	6
			$O\text{-}PO_4\text{-}P$		
0 (9:30 am)	4.7	4.7	4.7	5.1	5.1
1	4.3	4.3	4.7	4.5	4.8
2	4.6	4.6	4.4	5.0	5.4
3	4.8	4.4	4.6	4.8	5.5
4	4.8	4.8	4.8	5.0	5.5
5	4.9	4.9	4.9	5.0	5.7
MLSS	2,200	2,952	3,948	4,136	4,908

Table 4

BOD VARIATION
(Aeration Rate - 10 l/min.)

March 22, 1967

Components in Jugs

Jug No.	Quantity of Component Added	
	ML (liters)	Metrecal (ml)
2	15	7.5
3	15	15.0
4	15	22.5
6	15	30.0

Analytical Results (mg/l)

Aeration Time-Hrs	Jug No. 2	3	4	6
	$O\text{-}PO_4$ as P			
0 (9:00 am)	6.7	7.3	7.8	8.1
1	6.8	7.3	7.8	8.2
2	6.9	7.4	7.9	8.6
3	6.9	7.1	7.8	8.3
4	7.4	7.3	7.7	8.7
5	6.9	7.4	7.8	8.0
6	6.6	7.1	7.5	8.1
7	6.5	7.1	7.5	8.0
8	6.6	6.9	7.9	8.8
9	6.9	7.1	7.1	8.1
11	-	8.6	9.8	9.8
TSS	4,392	4,192	4,401	4,058

The results were similar to those of the suspended solids variation in that the soluble orthophosphate concentration did not change significantly. Thus, supplemental BOD was not beneficial to orthophosphate removal under the conditions studied.

3. Acclimation Studies

The hardness of Smithfield sewage was about 35 mg/l as $CaCO_3$ whereas that at San Antonio, Texas, was about 200 mg/l as $CaCO_3$. Thus, an opportunity was afforded to determine the effect of hardness on orthophosphate removal. Jug No. 5 in the suspended solids variation study on March 20 with existing hardness was subjected to a period of acclimation. A second acclimation jug was prepared on March 21, 1967. Calcium chloride and magnesium sulfate were added to increase hardness to about 200 mg/l $CaCO_3$.

The results and jug contents are shown in Tables 5 and 6. Base line results for both jugs were similar in that orthophosphate content increased slightly during the initial aeration period. Results from the aeration period following the first overnight acclimation period show 5 to 15 percent orthophosphate removal in both jugs.

Results from the aeration period following the second overnight acclimation period show 8 to 15 percent orthophosphate removal for the jug without hardness addition, and 90 percent orthophosphate removal for the jug with supplemental hardness. The jug without hardness was subjected to a third overnight acclimation period after which 65 percent of the soluble

Table 5

ACCLIMATION STUDY
Existing Hardness

Date	Aeration Time (hrs)	O-PO_4 as P (mg/1)	TSS (mg/1)	Remarks
3/20/67	0 (11:00 am)	5.8	3,004	Followed by a continuous
	1	6.8		feed from 6:00 pm to 8:30
	2	6.0		am of 30 ml Metrecal +
	3	6.0		544.4 mg KH_2PO_4 solution.
	4	5.8		Aeration rate = 15 1/min.
	5	6.0		
	6	6.1		
3/21/67	0 (8:30 am)	8.4	2,660	At 8:30 am settled solids,
	1	7.7		decanted 10 1 supernatant,
	2	7.4		added 10 1 PE. At 3:30 pm
	3	7.6		settled, decanted, and added
	4	7.8		10 1 PE. Continuously feed
	5	8.0		40 ml Metrecal + 544 mg
				KH_2PO_4 solution.
3/22/67	0 (10:00 am)	6.3	2,640	At 8:30 am settled, decanted,
	1	6.3		and added 10 1 PE. Added
	2	6.1		30 ml Metrecal, aeration
	3	5.9		rate reduced to 5 1/min.
	4	5.9		Hardness = 35.2 mg/1 $CaCO_3$.
	5	5.6		
	6	5.3		
	7	5.4		
	8	6.7		Added 30 ml Metrecal at
	10	5.7		9th hour.
3/23/67	0 (10:00 am)	7.1	3,264	At 9:00 am settled, decanted,
	1	6.6		and added 10 1 primary
	2	6.6		effluent. Hardness = 36.0
	3	6.1		mg/1 $CaCO_3$.
	4	5.6		
	5	5.1		
	6	5.2		
	7	4.4		
	8	4.3		
	9	3.7		
	10	3.5		
	12	3.4		At 13th hour, added 15
	14	3.4		ml Metrecal.
	15	2.8		
	16	2.6		
	17	2.5		

Table 6

ACCLIMATION STUDY

Supplemental Hardness

Date	Aeration Time (hrs)	O-PO_4 as P (mg/1)	TSS (mg/1)	Remarks
3/21/67	0 (9:30 am)	4.7	2,200	Starting components = 3.78 1 RS, 1.22 1 FE, 10 1 PE. Aeration rate = 15 1/min. At 3:30 pm settled, decanted and added 10 1 PE. At 8:00 pm, added 40 ml Metrecal + 2.2 gm $CaCl_2$ + 0.56 gm $MgSO_4$. Reduced aeration rate to 5 1/min.
	1	4.3		
	2	4.6		
	3	4.8		
	4	4.8		
	5	4.9		
3/22/67	0 (10:00 am)	5.6	1,770	At 8:30 am, settled, decanted, and added 10 1 PE. Added 30 ml Metrecal. Hardness = 240 mg/1 $CaCO_3$.
	1	5.6		
	2	5.5		
	3	5.4		
	4	5.2		
	5.5	5.0		
	6	4.8		
	7	4.9		
	8	5.1		At 9th hour, added 30 ml Metrecal.
3/23/67	0 (10:00 am)	6.8	3,024	At 9:00 am, settled, decanted, and added 10 1 PE. Hardness = 231.2 mg/1 $CaCO_3$.
	1	6.3		
	2	6.3		
	3	5.8		
	4	5.3		
	5	4.8		
	6	4.5		
	7	3.9		
	8	3.2		
	9	2.8		
	10	2.4		
	12	1.8		
	13	1.0		
	14	0.9		
	15	0.8		
	16	0.7		
	17	0.7		

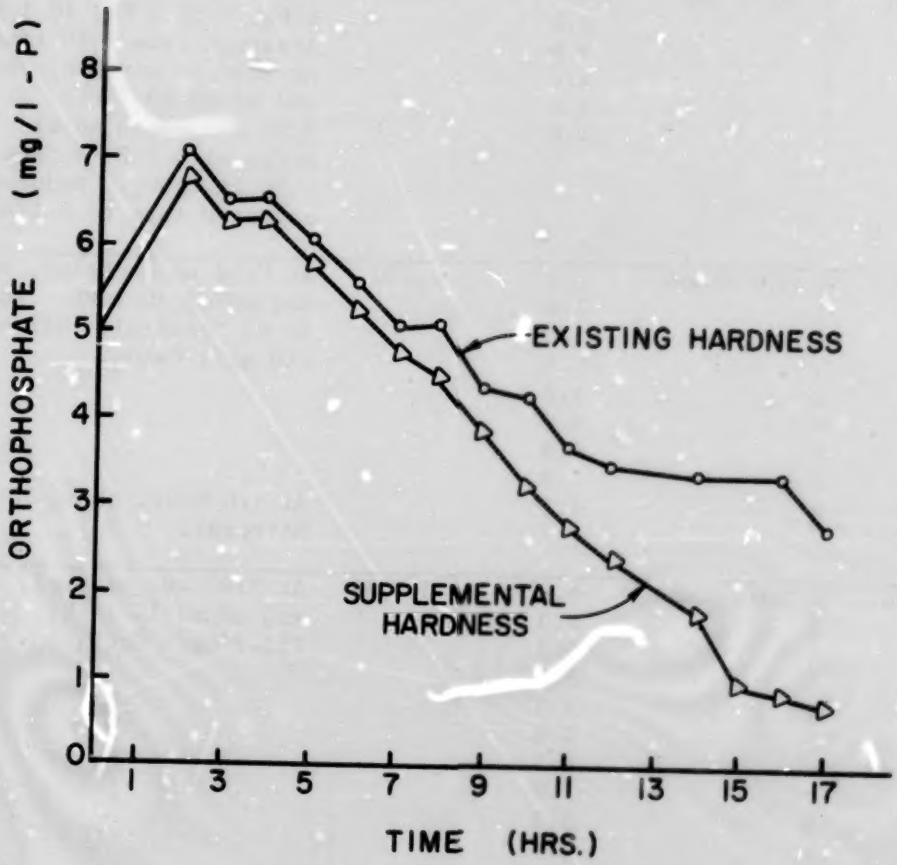

FIGURE 3 - METRECAL AND HARDNESS ADDITION

orthophosphate was removed (Figure 3). After acclimation of the sludge, the wastes were concluded amenable to the biological orthophosphate removal process. The results also indicate that hardness affects the removal process. The extent of its importance cannot be determined from the limited tests. The most significant observation concerning hardness is that the system with increased hardness responded sooner and to a higher degree.

It should be pointed out that the final aeration period for both jugs was abnormally long. Generally, the aeration period is 6 to 8 hours. In these studies, the aeration was continued through 17 hours due to continued response of the jugs.

Sewage Characterization

A related program was to characterize samples from the various unit processes of activated sludge plants with regard to selected chemical parameters. Primarily the intent was to search for trends or correlatable functions within or between various chemical parameters which would be useful in defining the phosphate removal process. Not infrequently phosphate removal realized from jug aeration was higher than that occurring in the aeration tanks. During such instances, the probability of identifying gross differences of possible significance was greatly enhanced. The results are given in a separate report.[2]

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[2]Lively, L. D., et al., "Phosphate Removal by Activated Sludge, Waste Characterization," USDI, FWPCA, Robert S. Kerr Water Research Center, Ada, Oklahoma. 1968.

Microbiological Studies

The microbiological studies conducted during the amenability program were divided into two phases. Phase I consisted of selecting predominate colonial types, transferring of such agar slants, and transporting to the Ada laboratory for identification. The final portion of this phase has been completed, and the results are in a separate report.[3] Phase II consisted of determining bacterial number by the total plate count method from various plant and aeration jug samples. A correlation of phosphate removal and bacterial population was sought. There was no apparent relationship between suspended solids content and bacterial contents. The bacterial counts remained essentially constant through the aeration tanks but showed a slight increase during jug runs. A slight change in count was noted during the course of the acclimation studies.

There was no major difference in bacterial counts during these studies. From these data, it was concluded that if bacterial counts and phosphate removal were related, this was not detectable by the methods employed.

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[3]Moyer, J. E., et al., "Survey of Activated Sludge Treatment Plants for Predominant Bacterial Types," USDI, FWPCA, Robert S. Kerr Water Research Center, Ada, Oklahoma. 1968.

SUMMARY

Studies conducted at the Smithfield, North Carolina activated sludge waste treatment plant on March 20-24, 1967, indicate that orthophosphate was not removed by the plant's secondary treatment process.

The aeration tanks are single-pass with a length-width ratio of 3.5:1. Dye tracer studies showed a dispersion index (t_{90}/t_{10}) of 7 and a modal detention time equal to 14 percent of the displacement time. Forty (40) percent of the mixed liquor receives less than 2 hours of aeration and 60 percent less than 3 hours.

The plant mixed liquor suspended solids varied from 4,000 to 4,500 mg/l during the study. The return sludge averages 50 and 75 percent of the high and low flow periods, respectively.

Pilot studies were conducted in aerated jugs to determine the effect on orthophosphate removal of various concentrations of mixed liquor suspended solids, biochemical oxygen demand, sludge viability, and sludge acclimation. Soluble orthophosphate concentration underwent little change during the suspended solids and BOD studies. Low soluble orthophosphate removal was observed during the sludge viability studies. The return sludge, after a period of acclimation and supplemented with "hardness," removed 90 percent of the orthophosphate sample; a control without supplemental "hardness' removed 65 percent. Maximum orthophosphate removal experienced during these studies was 90 percent.

CONCLUSIONS

Plant Studies

1. Limited studies indicate that the Smithfield, North Carolina sewage treatment plant is not removing a significant quantity of soluble orthophosphate.

2. The aeration tanks exhibit a high degree of longitudinal mixing and severe short circuiting.

3. The Smithfield plant's aeration time is insufficient for significant soluble orthophosphate removal, based on the San Antonio findings.

4. Aeration tank detention time might be improved by modification of the tanks from a parallel to a series flow pattern.

Jug Studies

1. Sludge at the Smithfield plant was not capable of removing soluble orthophosphate without acclimation.

2. Bacterial plate count did not correlate with soluble orthophosphate removal.

3. Sludge supplemented with "hardness" subjected to a period of acclimation removed a greater quantity of soluble orthophosphate than an acclimated sludge without supplemental "hardness." Carriage water "hardness" appears to be an important factor in regard to magnitude of soluble orthophosphate removal or to the time required to acclimate sludge.

RECOMMENDATIONS

The sewage and sludge in their present state are not amenable to biological orthophosphate removal. Sludge acclimation is possible and necessary to realize orthophosphate removal.

In its present state, the plant is not recommended for demonstration purposes. Operational changes and modifications as follows would be necessary prior to such utilization and; even so, a second amenability study would be desirable before making a commitment.

1. Compartmented aeration tank or putting the tank in series to obtain desired detention and plug-flow capability.

2. Decrease MLSS concentration to produce a desirable BOD loading.

3. Regulate air flow to produce a DO content of at least 2.0 mg/1 at end of the aeration tanks.

4. Reduce sludge age to three days, nominal.

APPENDIX

CHEMICAL PROCEDURES

Tests and Procedures

Sample Preparation

Samples collected for analyses in the field were processed as outlined in the following procedures.

1. Orthophosphate

In the field, samples processed for orthophosphate were immediately filtered through prefolded Schleicher and Schuell* No. 588 filters and the filtrate fed by use of the automatic sampler to a Technicon* AutoAnalyzer. The method was that of Gales and Julian[4] involving preliminary filtration followed by 40:1 dilution. The manifold and reagents were modified to deliver approximately those amounts specified by Standard Methods.[5]

2. Total Hardness

In the field, whole samples after filtration through Schleicher and Schuell No. 588 filters were analyzed for total hardness by Standard Methods. Centrate samples were analyzed identically but received no filtration.

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*See Page 25.

[4]Gales, M. E., Jr.,and E. C. Julian, "Determination of Inorganic Phosphate or Total Phosphate in Water by Automatic Analysis." Presented at the 1966 Technicon Symposium on Automation in Analytical Chemistry.

[5]Standard Methods for the Examination of Water and Wastewater, 12th Edition, (Orthophosphate Procedure B), pp. 234-236. 1965.

3. Solids

Tests for total suspended and total volatile suspended solids were conducted according to Standard Methods.[6] Reeve Angel* 2.4 cm glass fiber filters grade 934AH were used in lieu of asbestos mats. Gooch* crucibles were fired at 600°C, cooled, the mats placed in the crucibles and dried at 103°C for at least 1 hour before initial weighing. At intervals crucibles with filters were subjected to 600°C furnace temperatures to check for weight loss due to the filter. Total and total volatile solids were determined according to Standard Methods.[7]

4. Dissolved Oxygen

Measurements were made in situ with a YSI Model 51 Oxygen Meter* equipped with a Model 5103 oxygen/temperature probe. The meter was calibrated against the Azide Modification of the Winkler Method described in Standard Methods.[8] The meter was also calibrated against saturated air at the temperature of the test medium.

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*Mention of products and manufacturers is for identification only and does not imply endorsement by the Federal Water Pollution Control Administration or the U. S. Department of the Interior.

[6]Standard Methods for the Examination of Water and Wastewater, 12th Edition, (Methods C and D), pp. 424-425. 1965.

[7]Standard Methods for the Examination of Water and Wastewater, 12th Edition, (Methods A and B), pp. 423-424. 1965.

[8]Standard Methods for the Examination of Water and Wastewater, 12th Edition, (Method A), pp. 406-410. 1965.

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